A Comparison of Results from NASA's Meteoroid Engineering Model to the Long Duration Exposure Facility Cratering Record

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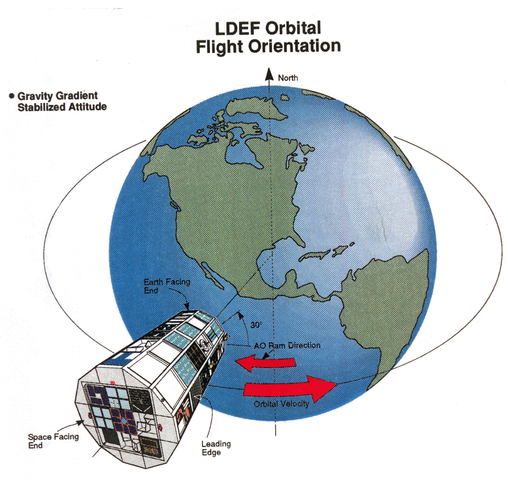
We present the first comparison between LDEF meteoroid impact data and NASA's Meteoroid Engineering Model (MEM)

The Long Duration Exposure Facility (LDEF)



- 480 km orbit from April 1984 to January 1990
- Dodecahedron shape, $\sim 9.1\,\mathrm{m} \times 4.3\,\mathrm{m}$
- Fixed orientation relative to gravity gradient and ram direction
- Careful identification of craters on all 14 surfaces
- Crater count data from Humes (1995), which had a limiting lip diameter of $d_{lip} \geq 1\,\mathrm{mm}$
- Chemical analysis on two surfaces: 3 and 11
- Assume no orbital debris craters on space-facing side

NASA's Meteoroid Engineering Model (MEM)

MEM Release 2 (MEMR2) is NASA's state-of-the-art model for the sporadic meteoroid environment:

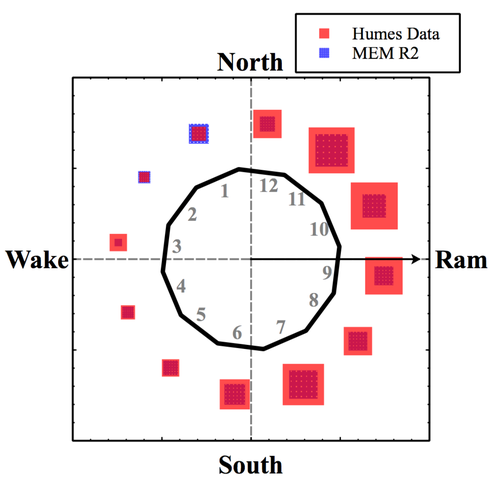
- Mass range of $10^{-6}\,\mathrm{g} - 1\,\mathrm{g}$
- Accounts for spatial and velocity distribution of meteoroids
- Assumes meteoroid density of $\rho_m = 1\,\mathrm{g\,cm^{-3}}$

MEMR2's interplanetary meteoroid flux matches that of Grün et al. (1985), which is based in part on in-situ experiments. However, Grün did not make use of LDEF data. LDEF therefore presents a new opportunity to test MEMR2's predictions.

Large Craters on LDEF

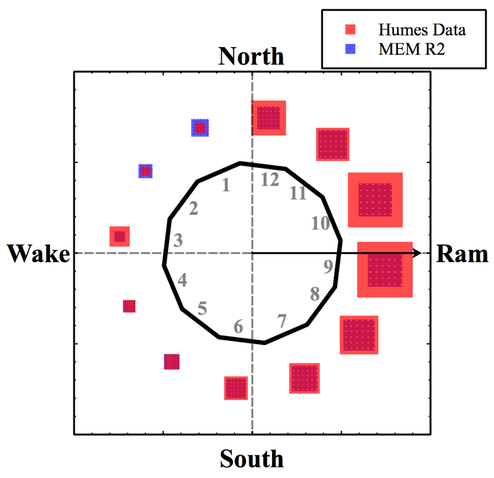
Surface	Label	Craters	Area (m^2)
1		2	3.84
2		1	2.26
3	Wake	3	1.48
4		2	2.66
5		3	2.66
6	South	9	3.26
7		17	3.69
8		8	1.08
9	Ram	14	0.913
10		22	1.48
11		21	3.84
12	North	8	1.33
13	Space	17	5.48
14	Earth	1	8.16

Results: Crater Counts



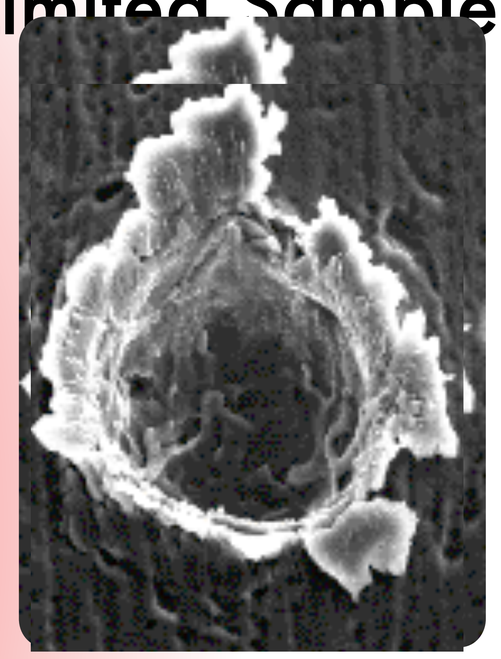
Surface	Observed	OD	Meteoroids	MEM
1	2	–	–	3.95
2	1	–	–	1.61
3 (Wake)	3	0.3	2.7	0.91
4	2	–	–	1.71
5	3	–	–	2.20
6 (South)	9	–	–	4.25
7	17	–	–	8.03
8	8	–	–	3.5
9 (ram)	14	–	–	3.56
10	22	–	–	5.42
11	21	9.45	11.55	10.46
12 (North)	8	–	–	2.27
13 (Space)	17	0	17	11.40

Surface	Observed	Observed (OD corrected)	MEM
1	$0.159^{+0.147}_{-0.094}$	–	0.49
2	$0.135^{+0.168}_{-0.135}$	–	0.34
3 (Wake)	$0.617^{+0.472}_{-0.370}$	$0.555^{+0.454}_{-0.338}$	0.30
4	$0.229^{+0.213}_{-0.139}$	–	0.31
5	$0.343^{+0.275}_{-0.206}$	–	0.40
6 (South)	$0.890^{+0.455}_{-0.330}$	–	0.63
7	$1.485^{+0.619}_{-0.437}$	–	1.05
8	$2.368^{+1.214}_{-0.918}$	–	1.56
9 (Ram)	$4.911^{+2.092}_{-1.481}$	–	1.87
10	$4.792^{+1.873}_{-1.284}$	–	1.76
11	$1.763^{+0.684}_{-0.494}$	$0.951^{+0.476}_{-0.309}$	1.31
12 (North)	$1.923^{+0.961}_{-0.711}$	–	0.82



Results: Flux Ratios

A Crater Limited Sample



A crater on LDEF as imaged by the Meteoroid and Debris Special Investigation Group at NASA's Johnson Space Center

We use the modified Cour-Palais equation to determine the limiting mass at which a a crater depth of lip diameter $d_{lip} = 1\,\mathrm{mm}$ could be produced. This corresponds to an interior crater diameter of $d = 750\,\mu\mathrm{m}$. This mass (m) is related to the meteoroids velocity normal to the spacecraft surface ($v_\perp$) and density (ρ_m) as

$$m = \frac{\pi}{6}\left(\frac{0.527 d}{5.24} BH^{0.25} \rho_m^{-4/27} \left(\frac{v_\perp}{c_t}\right)^{-2/3} \rho_t^{1/2}\right)^{54/19}$$

with $BH = 90$, $c_t = 6.1\,\mathrm{km\,s^{-1}}$, and a target density of $\rho_t = 2.70\,\mathrm{g\,cm^{-3}}$. The factor of 0.527 converts the interior crater diameter into a crater depth.

Orbital Debris

Orbital debris estimates come from the Chemistry of Micrometeoroids Experiment (Hörz et al 1995):

- $\sim 10\%$ of impacts on Surface # 3 (wake) are from orbital debris
- $\sim 45\%$ of impacts on Surface # 11 (north-ram) are from orbital debris

Towards the Future

We have developed a framework to compare future versions of MEM with the LDEF cratering record. Any changes in MEM's directionality, speed distribution, or meteoroid bulk density will ultimately change the predicted crater counts on each spacecraft surface. Validating environment models against *in-situ* crater data such as LDEF helps ensure an accurate assessment of the risk meteoroid impacts pose to future spacecraft missions.

Acknowledgments

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Summary

- Agreement between MEMR2 and observations usually to within $\sim 50\%$
- Discrepancy is direction-dependent
- Largest discrepancy is on northern wake-facing sides
- Flux ratios generally in agreement between model and data; albeit with large statistical uncertainites

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